Technology-based learning interventions on mathematical problem-solving: a meta-analysis of research in Indonesia

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Article Info

ABSTRACT

Mathematical problem-solving is important for learning mathematics and is needed in the 21st century. In the 21st century, education technology has been complementing every learning activity. Research on learners' mathematical problem-solving improvement increased rapidly over the last few decades. This study examined the effectiveness of technology-based mathematics learning interventions on learners' mathematical problem-solving at all levels of education in Indonesia. The researchers only took meta-analysis research from 2015 to 2023 from indexing databases, such as Scopus, Web of Science, Google Scholar, and Science and Technology Index (SINTA) indexers. The collected research articles were from only national journals in Indonesia. The screened data became the research results, containing the mean, standard deviation, number of samples (N), and the scale used in the research. This research had 19 independent studies in this meta-analysis. The data analysis applied meta-analysis, specifically the mean effect size value. The results of data analysis using Jeffrey's Amazing Statistics Program (JASP) software showed the effective implementation of innovative and fun technology-based mathematics learning interventions. These findings highlighted the importance of incorporating technology into mathematics education and its potential for improving learners' problem-solving skills.

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1. INTRODUCTION

One of the goals of 21st-century education is to develop students' problem-solving skills [1]–[4]. The development of problem-solving skills is inseparable from learning mathematics. Mathematical competence in the 21st century requires students to keep up with information and communication technology (ICT) and rapid digitalization [5]. The mathematical problem-solving skill development in the 21st century should use technology-based mathematics learning.

Problem-solving is a vital skill in the 21st century and is relevant to most academic activities and professional worlds [6], [7]. Mathematical problem-solving skill development is one of the most important goals of learning mathematics [8]. Learners must develop problem-solving skills to manage complex problems [9]. Leaners also need this skill both in social life and in the world of work later [10]. An individual mindset

influenced problem-solving skills indirectly. The moderating factor of this influence is - solving mathematical problems [11]. Therefore, learners must develop the mindset needed for 21st-century skills [12].

In the last few decades, many studies investigated the potential mathematics learning interventions to improve the quality of learning and learning outcomes [13]. Mathematics learning focuses on the students' mathematical skills to determine mathematical task completion and problem-solving success [14]. Mathematics skill refers to the implementation of mathematical concepts and processes to solve various mathematics problems flexibly and effectively [15]. Thus, problem-solving is important for the skill to develop their mathematical power and increase their confidence and competence in mathematical tasks.

Additionally, teachers can play an important role in supporting students' mathematical power by providing a supportive learning environment, encouraging critical thinking and problem-solving, and giving students opportunities to engage in mathematical tasks and activities that challenge their current understanding [16]. Teachers can also provide feedback and support that helps students identify areas for improvement and develop their mathematical power over time. In conclusion, mathematical power is a critical aspect of mathematical learning that has a significant impact on students' success in mathematical tasks and problem-solving. By providing effective mathematics learning interventions and supporting teachers, we can help students develop their mathematical power and improve their learning outcomes.

Technology is a learning challenge in the era of digital disruption [17]. Various studies in Indonesia and even the world have focused on technology-based mathematics learning interventions. The results of these research have proven that intervention in mathematics learning can improve students' mathematical abilities [18]–[20]. However, in Indonesia, there are still many teachers who do not take advantage of existing research results. Mathematics teachers who tend to use a teacher-centered learning approach still dominated in Indonesia [21]. The research by Sumardi *et al.* [22] also showed that most of the learning used a teacher-centered learning approach. The use of conventional methods results in the underdevelopment of students' higher-order thinking (HOT). The process of measuring problem-solving was often neglected in learning. If the teacher maximized the learning and assessment process, learners' mathematical problem-solving will be optimal. For example, the application of assessment strategies such as the structure of the observed learning outcomes (SOLO) taxonomy, the higher-order thinking skills model, performance appraisal, authentic assessment, dynamic assessment, and others have been shown to strengthen students' mathematical problem-solving skills [23].

The results of research on mathematics learning interventions, in general, can affect learners' mathematical abilities. Khalid *et al.* [24] in their research resulted that the effect of the creative problem solving in teaching mathematics affected the mathematical problem-solving ability of all students. In addition, the results of other studies showed that learning with the problem-based learning model can improve learners' mathematical problem-solving abilities [25]–[31]. The applied model or learning strategy may also include the availability of media or teaching materials to ease the learners. Thus, they can develop mathematical problem-solving. Suratno and Waliyanti [32] applied a blended learning model assisted by GeoGebra, information technology and communication [33], comics [34], learning games [35], [36], and so on whose estuary can improve students' mathematical problem-solving. This indicates that technology-based mathematics learning interventions with innovative and fun learning can positively influence learners' mathematical problem-solving.

Various perceptions are observable in mathematical problem-solving. Skills related to mathematics are focused on mathematic-task completion performance. On the other hand, mathematical problem-solving skill focuses on cognitive implementation and complex problem-solving skills with critical and logical thinking. This study applied the two terms to search related data of the meta-analysis scheme.

Various studies found that the average mathematical problem-solving of learners after being given an intervention shows good results. However, the results of existing research have not been generalized. So, the effectiveness of technology-based mathematics learning interventions in Indonesia on problem-solving has not been identified. The research question is: how is the effectiveness of technology-based mathematics learning interventions for solving students' math problems at all levels of education in Indonesia? This study will reveal the effectiveness of technology-based mathematics learning interventions on mathematics problem-solving in Indonesia by analyzing various previous studies. Based on the problems, this study aimed to examine the effectiveness of the intervention in technology-based mathematics learning on learners' mathematical problem-solving at all levels of education in Indonesia through a meta-analysis of research in the period 2015 to 2023.

2. RESEARCH METHOD

Meta-analysis is research conducted by summarizing, reviewing, and analyzing research data from several similar research results and ending with global conclusions. The theme of this research is the impact of technology-assisted mathematics learning in optimizing students' math problem-recovery skills. Therefore, the data population in this article is a review of all research results that explain the average problem-solving skills after receiving learning interventions that integrate technology.

2.1. Literature search

This study used a mean meta-analysis design by calculating the effect size of the random effect model. This research data collection technique was through the documentation by collecting similar research that already exists. To find studies on mathematical problem-solving, researchers used a systematic literature search through electronic databases, including Scopus, Web of Science, Google Scholar, and the Science and Technology Index (SINTA) indexer applicable to national journals in Indonesia. The keywords used include problem-solving, mathematics problem-solving, and ICT. The documents used in this research are journal articles and online proceedings.

2.2. Inclusion criteria

The population in this study were all articles of research results regarding interventions in technology-based mathematics learning on students' mathematical problem-solving at all levels of education in Indonesia. The research sample was taken using the purposive sampling technique. The sample was determined based on the suitability of the research theme and used the following criteria: i) measuring learners' mathematical problem-solving through average scores; and ii) reporting the mean, standard deviation, number of samples, and range of data.

2.3. Coding

The coding of the article as a study to be mapped considers the following variables: year of publication (2015-2023), school level, number of samples, region, and average effect size. The coding procedure was carried out by: i) recording the effect size for each independent sample in the study; and ii) if a study reports on the average mathematical problem-solving of students from different subsamples such as grouping students with high, medium, and low abilities, then the coding is done separately. From 317 articles with the same criteria and research results were collected, a total of 90 articles with 112 independent studies met the coding criteria. Articles that participated in coding but whose information was incomplete, such as no explanation of the number of samples, data ranges, and standard deviation values were not included in the study sample. After coding was completed, 17 articles were obtained according to the inclusion criteria and 1 article had several independent samples. The study used a whole research sample, namely 19 independent studies. The determination of the sample used in this study is briefly described in Figure 1.
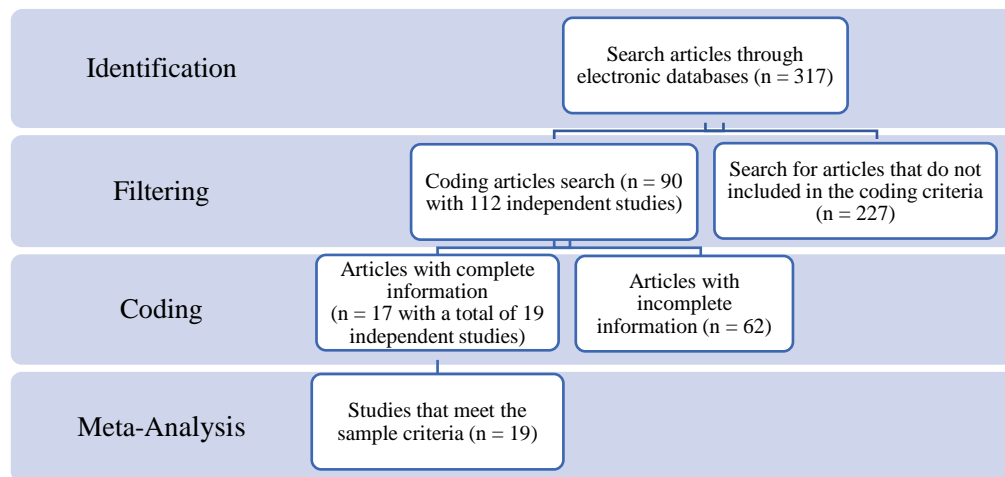

Figure 1. Schematic of the number of researchers analyzed

2.4. Data analysis technique

The researchers used quantitative data analysis in this meta-analysis with Microsoft Excel and Jeffrey's Amazing Statistics Program (JASP). Microsoft Excel was useful for collecting the effect size (ES), transforming the ES scale, and calculating the standard error (SE). Then, the researchers determined the whole and aggregated effect size with the JASP program. In general, the data analysis process, includes: i) applying a heterogeneity test; ii) determining the summary effect or aggregate effect size; iii) developing forest plots and their interpretations; and iv) evaluating publication bias [37].

3.   RESULTS AND DISCUSSION
3.1. Results

This study aims to examine the impact of interventions in technology-based mathematics learning at all levels of education in Indonesia, starting from elementary school (ES), junior high school (JHS), senior high school (SHS), vocational high school (VHS), to higher education (college). A total of 317 articles were found through electronic databases, but only 19 articles were used as research data. Table 1 shows the generated data from 19 studies.

Table 1. Studies in meta-analysis

No.	Study	Intervention
1	[38]	Problem-based learning (PBL) assisted by QR code
2	[39]	Online problem posing
3	[40]	Trigonometry learning kit with a STEM approach
4	[41]	Visual basic for Microsoft Word application
5	[42]	Blended learning model
6	[43]	MURDER cooperative learning model through Edmodo
7	[35]	Learning using Quizizz
8	[36]	Multi-Representation Discourse (MRD) learning assisted by the dragon box puzzle game
9	[44]	Online Interactive Apps
10	[33]	Information technology and communication based lesson study
11	[45]	Dynamic Mathematics Software GeoGebra
12	[46]	Instructional videos on an e-learning platform
13	[47]	Contextual learning with android-based learning media
14	[48]	Online project collaborative learning for all students, low-ability students, and high-ability students
15	[49]	Interactive learning media
16	[50]	Online-based M-APOS model
17	[32]	GeoGebra in problem-based learning

3.1.1. Heterogeneity test

Processing data for this meta-analysis using the JASP program. The researchers used Q-statistic for the heterogeneity test. Table 2 and Table 3 show the Q-value and p-value of the fixed and randomized effects. Table 2 shows the value of degrees of freedom (df) obtained from the n-study (19-1=18). The heterogeneity result is observable from the q-value and the p-value of the residual heterogeneity line test. The obtained Q value is 1630.850 with the p-value<.001, lower than .05, indicating heterogeneous effect size. The results proved the model could estimate the mean effect size of the 19 studies analyzed.

Based on the calculation of residual heterogeneity estimates, the I^2 value is 99.047 with an interval of 98.329 and 99.599, indicating heterogeneous effect size due to sampling error. Thus, the effect size in the studies used was not the same. The researchers interpreted the summary effect with the random effects to avoid inaccuracy due to fixed-effect implementation.

Table 2. Heterogeneity test

Fixed and random effects	Q	df	p
Omnibus test of model coefficients	609.240	1	<.001
Test of residual heterogeneity	1630.850	18	<.001

Table 3. Residual heterogeneity estimates

Residual heterogeneity estimates	95% Confidence interval		
	Estimate	Lower	Upper
τ^2	158.025	89.480	377.598
τ	12.571	9.459	19.432
I^2 (%)	99.047	98.329	99.599
H^2	104.931	59.850	249.341

3.1.2. Summary effect (aggregate effect size)

The aggregate of the mean from 19 studies on student mathematics problem-solving interventions can be seen in the Coefficient Table. This aggregate of the mean shows the average problem-solving ability of students after receiving technology-based learning intervention. Complete results are presented in Table 4. Table 4 shows the summary effect at 78.037, the standard error (SEM) at 2.929, and the z value at 24.683. The p-value is lower than .05, or significant. The average effect size is 72.296, categorized as excellent. Figure 2 shows the aggregate mean results of the forest plot are 72.296 with a lower limit (LM) of 66.555, an upper limit (UL) of 78.037, and a confidence interval of 95% or significant.

Table 4. Summary effect (aggregate effect size)

| | Coefficients | | | | 95% Confidence interval | |
	Estimate	Standard error	z	p	Lower	Upper
Intercept	72.296	2.929	24.683	<.001	66.555	78.037

Forest plots contain information about the study analyses and the effect sizes. The forest plot has black rectangles to indicate the size effect. The right-side rectangles have high effect sizes. The size of the black rectangle shows the significance of the size effect. Figure 2 shows the effect sizes are varied. The magnitude is between 66.56 to 78.04.
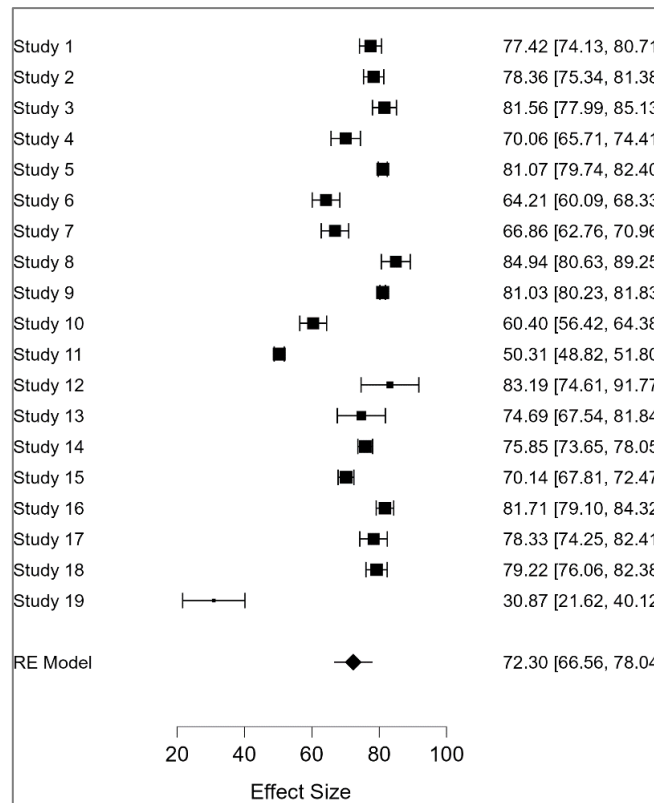
Figure 2. Forest plot

3.1.3. Evaluation of publication bias

Evaluation of publication bias aims to investigate the presence of publication bias. A good meta-analysis should not contain publication bias. This indication can be seen in the funnel plot as presented in Figure 3. In the funnel plot, the X-axis shows the effect size value of each study. The center line (vertical line) shows the average effect size of the analyzed studies. The dots show the distribution of the study size effect on the standard error. The Y axis shows the standard error of the studies. Low points led to high standard error. Figure 3 shows the relatively symmetric funnel plot, indicating no publication bias.

The funnel plot did not provide strong evidence of free-bias publicity because the plot relied on visual aid. Thus, the plot is subjective [51]. The researchers used the rank correlation test to support the funnel plot result. Table 5 determines the publication bias indication from the p-value. The applied criterion for a symmetrical condition is a p-value higher than 0.05. The rank correlation table shows p=.139, higher than .05, or a symmetrical funnel plot. The results proved no publication bias in terms of the meta-analytical studies. Table 6 provides the Egger test results of publication bias.
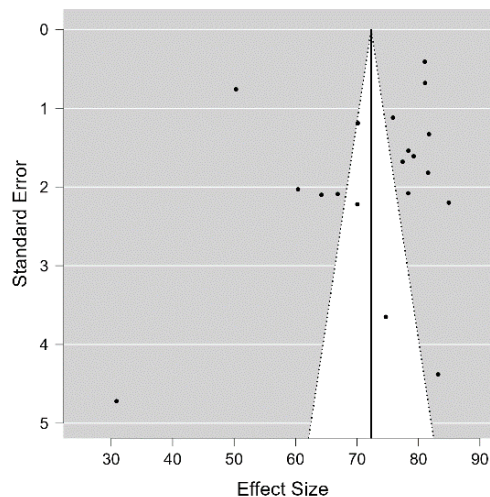
Figure 3. Funnel plot

Table 6 shows the p-value to determine the symmetrical funnel plot indication. The funnel plot is deemed symmetric if the p-value is higher than .05. The Egger Test shows p=.139, higher than .05, or symmetrical. The results proved no biased publication in terms of the meta-analytical studies conducted.

Table 5. Rank correlation

Rank correlation test for Funnel plot asymmetry		
	Kendall's τ	p
Rank test	-.240	.139

Table 6. Egger test

Regression test for Funnel plot asymmetry (Egger's test)		
	z	p
Sei	-1.481	.139

3.2. Discussion

The meta-analysis found the objective of teaching mathematics was to develop students' problem-solving skills [52]. The meta-analysis results showed the learners excellently solved math problems at all levels of education because of innovative and fun technology. In this research, the technology intervention was explicit and systematic. The teacher taught the steps of solving mathematical problems with logical development skills [53] and technology. The current results were consistent with the previous studies. Mathematics learning intervention positively influenced learners' mathematical skills [54]–[58]. The heterogeneity test obtained an I² value of 99.047 or 99% (higher than 75%) indicating heterogeneous effect size [59]. High heterogeneity [60] indicated variability in most measurements [61]. Thus, the researchers applied a random effect model to calculate the combination of effect sizes [62].

The summary effect or average aggregate generated from these 19 meta-analytical studies is 72.296. The value indicated an excellent category of mathematical problem-solving skills after receiving technology-based learning. The results proved mathematics learning interventions improved students' mathematical problem-solving [63]. The researchers found 14 studies with greater mean than the obtained aggregate. In this research, all studies showed the effectiveness of technology-based mathematics learning intervention on mathematics problem-solving skills at all education levels in Indonesia. Several studies also found significant effects of a technology-based intervention on learners' problem-solving skills [64]–[66], the learning process [67]–[69].

The intervention facilitated students to study independently and in groups. They could understand and use strategies for problem-solving systematically and develop reflexive and creative thinking [70]. Herrada and Baños [71] reinforced that the learning intervention improved cooperative learning in the classroom. The intervention supported the knowledge and skill acquisition and transfer to improve the quality of education. The intervention also provided scaffolding to facilitate solving unstructured problems [72].

Indonesia is a diverse country with various cultures, religions, ethnicity, language, and customs [73]. Thus, every learner has a variety of different characteristics. Teachers had to plan mathematics learning intervention strategies based on the characteristics of their learners [74]. They also had to consider the strategies and learners' competencies within the material dimension. Teachers had to develop learning strategies based on technology to improve mathematics learning [75].

This meta-analysis study has several limitations in literature collection, namely: i) difficulty in finding articles on the mapped topics from reputable journals, so most articles come from journals indexed by SINTA (Indonesia); ii) difficulty in obtaining articles whose research locations are in Eastern Indonesia; and iii) difficulty in getting articles with the same level of education. This research recommends future researchers promote related research to determine the most suitable intervention or learning approach for the teachers. Teachers need to make new interventions into the practice of technology-based mathematics learning in the classroom by adjusting the curriculum and student characteristics. The process of assessing the right problem-solving also needs to be considered by the teacher to measure students' optimal mathematical problem-solving.

4. CONCLUSION

This meta-analysis research examines the effectiveness of technology-based mathematics learning interventions on students' mathematical problem-solving at all levels of education in Indonesia in the 2015 to 2023 period. The results show that innovative and fun technology-based mathematics learning interventions positively influenced math problem-solving students in Indonesia with a mean effect size of 72.296. Innovative and fun technology-based mathematics learning interventions effectively improved mathematics problem-solving for students in Indonesia at all levels of education in Indonesia. This research could be the consideration for mathematics teachers in Indonesia to provide innovative and fun technology-based mathematics learning interventions so that mathematics learning is not monotonous and conventional. Teachers must develop and improve students' mathematical problem-solving. However, an appropriate and standardized problem-solving assessment process in Indonesia also is important to produce optimal student mathematical problem-solving.

REFERENCES

[1] G. Gunawan, A. Harjono, M. Nisyah, M. Kusdiastuti, and L. Herayanti, "Improving Students' Problem-Solving Skills Using Inquiry Learning Model Combined with Advance Organizer," *International Journal of Instruction*, vol. 13, no. 4, pp. 427–442, 2020, doi: 10.29333/iji.2020.13427a.

[2] P. N. Iwuanyanwu, "Nature of Problem-Solving Skills for 21st Century STEM Learners: What Teachers Need to Know," *Journal of STEM Teacher Education*, vol. 55, no. 1, pp. 27–40, 2020, doi: 10.30707/jste55.1/mmdz8325.

[3] C. Kivunja, "Exploring the Pedagogical Meaning and Implications of the 4Cs 'Super Skills' for the 21st Century through Bruner's 5E Lenses of Knowledge Construction to Improve Pedagogies of the New Learning Paradigm," *Creative Education*, vol. 06, no. 02, pp. 224–239, 2015, doi: 10.4236/ce.2015.62021.

[4] Z. K. Szabo, P. Körtesi, J. Guncaga, D. Szabo, and R. Neag, "Examples of Problem-Solving Strategies in Mathematics Education Supporting The Sustainability of 21st-Century Skills," *Sustainability (Switzerland)*, vol. 12, no. 23, pp. 1–28, 2020, doi: 10.3390/su122310113.

[5] Riyadi, T. J. Syarifah, and P. Nikmaturrohmah, "Profile of Students' Problem-Solving Skills Viewed from Polya's Four-Steps Approach and Elementary School Students," *European Journal of Educational Research*, vol. 10, no. 4, pp. 1625–1638, 2021, doi: 10.12973/EU-JER.10.4.1625.

[6] S. Lamb, Q. Maire, and E. Doecke, "Key Skills for the 21st Century: an Evidence-Based Review," NSW Department of Education, 2017.

[7] L. English and J. Gainsburg, "Problem Solving in a 21st-Century Mathematics Curriculum," in *Handbook of International Research in Mathematics Education*, United States of America: Routledge, 2016, pp. 313–335. doi: 10.1007/978-3-642-00742-2.

[8] I. Marchiş, "Relation Between Students' Attitude Towards Mathematics and Their Problem Solving Skills," *PedActa*, vol. 3, no. 2, pp. 59–66, 2013.

[9] L. D. Permata, T. A. Kusmayadi, and L. Fitriana, "Mathematical Problem Solving Skills Analysis About Word Problems of Linear Program Using IDEAL Problem Solver," *Journal of Physics: Conference Series*, vol. 1108, no. 012025, pp. 1–6, 2018, doi: 10.1088/1742-6596/1108/1/012025.

[10] J. Voogt and N. P. Roblin, *21st Century Skills*. Enschede, Netherlands: University of Twente, 2010.

[11] J. Boaler, K. Brown, T. LaMar, M. Leshin, and M. Selbach-Allen, "Infusing Mindset through Mathematical Problem Solving and Collaboration: Studying the Impact of a Short College Intervention," *Education Sciences*, vol. 12, no. 694, pp. 1–21, 2022, doi:

10.3390/educsci12100694.

[12] M. M. Rahman, "21st Century Skill 'Problem Solving': Defining the Concept," *Asian Journal of Interdisciplinary Research*, vol. 2, no. 1, pp. 71–81, 2019, doi: 10.34256/ajir1917.

[13] R. E. Groth, "Introduction to Teaching and Learning Mathematics," in *Teaching Mathematics in Grades 6–12: Developing Research-Based Instructional Practices*, New York: SAGE Publications, Inc, 2012. doi: 10.4135/9781452244105.

[14] A. Baroody, A. J. Baroody, J. L. M. Wilkins, R. T. Coslick, and R. T. Coslick, *Fostering Children's Mathematical Power: An Investigative Approach To K-8 Mathematics Instruction*. London: Routledge, 1998.

[15] I. Kusmaryono, H. Suyitno, D. Dwijanto, and N. Karomah, "Analysis Instrument Test on Mathematical Power the Material Geometry of Space Flat Side for Grade 8," *AIP Conference Proceedings*, vol. 1867, pp. 1–14, 2017, doi: 10.1063/1.4994416.

[16] O. O. Kuku and S. O. Adeniyi, "Impact of Learning Interventions on Mathematics Achievement Among Learners with Hearing Impairment," *Contemporary Educational Researches Journal*, vol. 10, no. 4, pp. 131–143, 2020, doi: 10.4314/ajesms.v16i2.4.

[17] A. K. Putra, Sumarmi, A. Sahrina, A. Fajrilia, M. N. Islam, and B. Yembuu, "Effect of Mobile-Augmented Reality (MAR) in Digital Encyclopedia on The Complex Problem Solving and Attitudes of Undergraduate Student," *International Journal of Emerging Technologies in Learning*, vol. 16, no. 7, pp. 119–134, 2021, doi: 10.3991/ijet.v16i07.21223.

[18] S. Tan, L. Zou, and T. T. Wijaya, "Using Video Learning To Improve Students' Mathematical Ability," *Journal of Didactic Mathematics*, vol. 1, no. 3, pp. 117–126, 2021, doi: 10.34007/jdm.v1i3.364.

[19] M. Ulfa, Yerizon, and I. M. Arnawa, "The Influence of Using Computers in Mathematics Learning to Students Mathematical Ability," *Journal of Physics: Conference Series*, vol. 1742, no. 012045, pp. 1–6, 2021, doi: 10.1088/1742-6596/1742/1/012045.

[20] Y.-W. Lin, C.-L. Tseng, and P.-J. Chiang, "The Effect of Blended Learning in Mathematics Course," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 13, no. 3, pp. 741–770, 2017, doi: 10.12973/eurasia.2017.00641a.

[21] V. F. Rianasari, H. Julie, and M. S. Apriani, "Indonesian Mathematics Teachers' Responses Towards the Implementation of Distance Learning During Covid-19 Pandemic," *Proceedings of the 7th International Conference on Research, Implementation, and Education of Mathematics and Sciences (ICRIEMS 2020)*, 2021, vol. 528, pp. 383–390, doi: 10.2991/assehr.k.210305.055.

[22] L. Sumardi, A. Rohman, and D. Wahyudiati, "Does the Teaching and Learning Process in Primary Schools Correspond to the Characteristics of the 21st Century Learning?" *International Journal of Instruction*, vol. 13, no. 3, pp. 357–370, 2020, doi: 10.29333/iji.2020.13325a.

[23] F. Ukobizaba, G. Nizeyimana, and A. Mukuka, "Assessment Strategies for Enhancing Students' Mathematical Problem-solving Skills: A Review of Literature," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 17, no. 3, pp. 1–10, 2021, doi: 10.29333/ejmste/9728.

[24] M. Khalid, S. Saad, S. R. Abdul Hamid, M. Ridhuan Abdullah, H. Ibrahim, and M. Shahrill, "Enhancing Creativity and Problem Solving Skills Through Creative Problem Solving in Teaching Mathematics," *Creativity Studies*, vol. 13, no. 2, pp. 270–291, 2020, doi: 10.3846/cs.2020.11027.

[25] N. Yendra, A. Fauzan, and B. Junedi, "Development of Problem Based Learning (PBL) Learning Tools to Improve Mathematical Problem Solving Ability of Class VIII SMP/MTs Students," in *Proceedings of The 5th International Conference of Mathematics and Mathematics Education, 2021: Developing Mathematics, and Mathematics Educational Research Oriented to Sustainable Development Goals*, 2023. doi: https://doi.org/10.1063/5.0122385.

[26] H. Hendriana, T. Johanto, and U. Sumarmo, "The Role of Problem-Based Learning to Improve Students' Mathematical Problem-Solving Ability and Self Confidence," *Journal on Mathematics Education*, vol. 9, no. 2, pp. 291–299, 2018, doi: 10.22342/jme.9.2.5394.291-300.

[27] R. Rusnanda and S. Safwandi, "Improvement of Mathematical Problem Solving Ability Through Problem Based Learning Model in Applied Mathematics Course II in Industrial Engineering," *IOP Conference Series: Materials Science and Engineering*, vol. 506, no. 012025, pp. 1–5, 2019, doi: 10.1088/1757-899X/506/1/012025.

[28] A. Dorimana, A. Uworwabayeho, and G. Nizeyimana, "Enhancing Upper Secondary Learners' Problem-solving Abilities using Problem-based Learning in Mathematics," *International Journal of Learning, Teaching and Educational Research*, vol. 21, no. 8, pp. 235–252, 2022, doi: 10.26803/ijlter.21.8.14.

[29] D. Ponjen and Suparman, "Student worksheets design to improve problem-solving ability with problem-based learning," *International Journal of Scientific and Technology Research*, vol. 9, no. 3, pp. 4700–4705, 2020.

[30] M. Surur, I. N. S. Degeng, P. Setyosari, and D. Kuswandi, "The Effect of Problem- Based Learning Strategies and Cognitive Styles on Junior High School Students' Problem-Solving Abilities," *International Journal of Instruction*, vol. 13, no. 4, pp. 35–48, 2020, doi: https://doi.org/10.29333/iji.2020.1343.

[31] L. V. Putra, E. Suryani, O. S. Kinasih, and W. T. Utami, "Improving Mathematical Problem Solving Abilities of the Student With the Problem-Based Learning Approach," *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, vol. 10, no. 1, pp. 457–466, 2021, doi: 10.24127/ajpm.v10i1.3315.

[32] J. Suratno and I. K. Waliyanti, "The Integration of GeoGebra in Problem-Based Learning to Improve Students' Problem-Solving Skills," *International Journal of Research in Mathematics Education*, vol. 1, no. 1, pp. 63–75, 2023, doi: 10.24090/ijrme.

[33] H. S. Bintoro, Zaenuri, and Wardono, "Application of Information Technology and Communication-Based Lesson Study on Mathematics Problem-Solving Ability," *Journal of Physics: Conference Series*, vol. 1918, no. 4, pp. 1–6, 2021, doi: 10.1088/1742-6596/1918/4/042105.

[34] S. Suryatin and S. Sugiman, "Comic Book for Improving the Elementary School Students' Mathematical Problem Solving Skills and Self-Confidence," *Jurnal Prima Edukasia*, vol. 7, no. 1, pp. 58–72, 2019, doi: 10.21831/jpe.v7i1.10747.

[35] S. Setiyani, N. Fitriyani, and L. Sagita, "Improving Student's Mathematical Problem Solving Skills Through Quizizz," *JRAMathEdu (Journal of Research and Advances in Mathematics Education)*, vol. 5, no. 3, pp. 276–288, 2020, doi: 10.23917/jramathedu.v5i3.10696.

[36] N. Supriadi, K. Ramadhona, D. D. Pratiwi, and S. Widyawati, "Concept Understanding Skills and Mathematical Problem-Solving Skills in Algebraic Materials: The Effect of DMR Learning Model Assisted by Dragonbox Puzzle Game During The Covid-19 Pandemic," *Al-Jabar: Jurnal Pendidikan Matematika*, vol. 11, no. 1, p. 191, 2020, doi: 10.24042/ajpm.v11i1.8332.

[37] M. Borenstein, L. V. Hedges, J. P. T. Higgins, and H. R. Rothstein, *Introduction to Meta-Analysis*. United Kingdom: John Wiley & Sons, Ltd, 2009. doi: 10.1007/978-3-319-52636-2_287.

[38] Santoso, H. Ulya, and R. Rahayu, "Application of Problem Based Learning Assisted by QR Code to Improve Mathematical Problem-Solving Ability of Elementary Teacher Education Students," *Indonesian Journal of Mathematics Education*, vol. 2, no. 1, pp. 1–8, 2019, doi: http://dx.doi.org/10.31002/ijome.v2i1.1221.

[39] I. M. Suarsana, I. A. P. D. Lestari, and N. M. S. Mertasari, "The Effect of Online Problem Posing on Students' Problem-Solving Ability in Mathematics," *International Journal of Instruction*, vol. 12, no. 1, pp. 809–820, 2019, doi: 10.29333/iji.2019.12152a.

[40] A. N. Arivina and J. Jailani, "Development of Trigonometry Learning Kit with a STEM approach to improve problem solving skills and learning achievement," *Jurnal Riset Pendidikan Matematika*, vol. 7, no. 2, 2020, doi: 10.21831/jrpm.v7i2.35063.

[41] C. M. Pertiwi, E. E. Rohaeti, and W. Hidayat, "The Students' Mathematical Problem-Solving Abilities, Self-Regulated Learning, and VBA Microsoft Word in New Normal: a Development of Teaching Materials," *Infinity Journal l of Mathematics Education*, vol. 10, no. 1, pp. 17–30, 2020, doi: 10.22460/infinity.v10i1.p17-30.

[42] R. Ramadhani and S. Aisyah, "Students' Mathematical Problem Abilities Improvement Using Blended Learning Reviewed From The Initial Ability of Students," *IJEMS: Indonesian Journal of Education and Mathematical Science*, vol. 1, no. 3, pp. 11–18, 2020, doi: 10.30596/ijems.v1i2.4412.

[43] P. R. A. Saputra, S. Sariyasa, and I. N. Suparta, "MURDER Cooperative Learning Model through Edmodo Toward Mathematics Problem Solving and Motivation of Students," *International Journal on Emerging Mathematics Education*, vol. 4, no. 1, pp. 43–52, 2020, doi: 10.12928/ijeme.v4i1.15845.

[44] S. Wahyuningsih, D. Satyananda, A. Qohar, and N. A. Atan, "An Integration of 'Online Interactive Apps' for Learning Application of Graph Theory to Enhance Creative Problem Solving of Mathematics Students," *International Journal of Interactive Mobile Technologies*, vol. 14, no. 12, pp. 97–109, 2020, doi: 10.3991/IJIM.V14I12.15583.

[45] M. Mukhtar, R. A. Z. El Islami, D. Damanhuri, and F. M. Hamundu, "Information and Communication Technologies to Improve Problem Solving and Self-Efficacy: Exploring Geometry Learning Using Dynamic Mathematics Software GeoGebra," *International Journal of STEM Education for Sustainability*, vol. 1, no. 1, pp. 45–52, 2021, doi: 10.53889/ijses.v1i1.4.

[46] A. Salsabila and T. R. Pradipta, "Mathematical Problem Solving Ability: The Impact of Mathematics Learning Videos on an E-Learning Platform," *Al-Jabar: Jurnal Pendidikan Matematika*, vol. 12, no. 1, pp. 83–88, 2021, doi: 10.24042/ajpm.v12i1.8708.

[47] A. Yani, I. Prihatin, Hodiyanto, and Sumiati, "Android-Based Learning Media Design with Contextual Learning to Develop Problem-Solving Skills," *Jurnal Didaktik Matematika*, vol. 8, no. 2, pp. 148–159, 2021, doi: 10.24815/jdm.v8i2.18555.

[48] M. Yunus, P. Setyosari, S. Utaya, and D. Kuswandi, "The Influence of Online Project Collaborative Learning and Achievement Motivation on Problem-Solving Ability," *European Journal of Educational Research*, vol. 10, no. 2, pp. 813–823, 2021, doi: 10.12973/EU-JER.10.2.813.

[49] E. Hayati and Z. Amri, "Interactive Learning Media on Mathematics Problem Solving Elementary School Students," *Journal of Mathematics Education and Application (JMEA)*, vol. 1, no. 2, pp. 89–96, 2022, doi: 10.30596%2Fjmea.v1i2.10555.

[50] M. Ilmi, Makmuri, and E. D. Wiraningsih, "The Effect of The Online-Based M-APOS Model On Mathematics Problem-Solving Ability Reviewed From Students' Self-Esteem," *Jurnal Tarbiyah*, vol. 29, no. 1, pp. 1–16, 2022, doi: 10.30829/tar.v29i1.1266.

[51] S. Zhang, H. Huang, Q. Wu, Y. Li, and M. Liu, "The impacts of family treatment drug court on child welfare core outcomes: A meta-analysis," *Child Abuse and Neglect*, vol. 88, no. October 2018, pp. 1–14, 2019, doi: 10.1016/j.chiabu.2018.10.014.

[52] I. Rafi and Sugiman, "Problem Posing Ability Among Prospective Mathematics Teachers," *PYTHAGORAS: Jurnal Pendidikan Matematika*, vol. 14, no. 2, pp. 188–198, 2019, doi: https://doi.org/10.21831/pg.v14i2.29976.

[53] National Center on Intensive Intervention, "Principles for Designing Intervention in Mathematics," 2016.

[54] A. E. Jacobse and E. Harskamp, "A Meta-Analysis of the Effects of Instructional Interventions on Students' Mathematics Achievement," 2011.

[55] D. Juandi, Y. S. Kusumah, and M. Tamur, "A Meta-Analysis of the last two decades of realistic mathematics education approaches," *International Journal of Instruction*, vol. 15, no. 1, pp. 381–400, 2022, doi: 10.29333/iji.2022.15122a.

[56] H. Ulya and R. Rahayu, "Students' Mathematical Representation Ability in Kudus Local Wisdom-Based Open-Ended Learning," *Journal of Physics: Conference Series*, vol. 1823, no. 012102, pp. 1–7, 2021, doi: 10.1088/1742-6596/1823/1/012102.

[57] R. Rahayu, H. Ulya, Kartono, and Isnarto, "A Practicallity Analysis of Collaborative Assessment Model Based on Ethnomathematics," *Journal of Advanced Research in Dynamical and Control Systems*, vol. 11, no. 7, pp. 366–373, 2019.

[58] H. Ulya, R. Rahayu, and A. Riyono, "Integration of Products Assessment in Mind Mapping Learning to Enhance Mathematical Communication," *Journal of Physics: Conference Series*, vol. 1175, pp. 1–8, 2019, doi: 10.1088/1742-6596/1175/1/012142.

[59] E. S. Kriswanto, A. F. Pambudi, H. Retnawati, Siswantoyo, S. Arifin, and H. Putranta, "Effect of Leg Length on Running Speed of Sports and Health Sciences Students in Indonesia: A Meta-Analysis Study," *Journal of Physical Education and Sport*, vol. 21, no. 5, pp. 2697–2705, 2021, doi: 10.7752/jpes.2021.05359.

[60] B. Mullen, P. Muellerleile, and B. Bryant, "Cumulative Meta-Analysis: A Consideration of Indicators of Sufficiency and Stability," *Personality and Social Psychology Bulletin*, vol. 27, no. 11, pp. 1450–1462, 2001, doi: 10.1177/01461672012711006.

[61] J. E. Kong, C. Yan, A. Serceki, and H. L. Swanson, "Word-Problem-Solving Interventions for Elementary Students with Learning Disabilities: A Selective Meta-Analysis of the Literature," *Learning Disability Quarterly*, vol. 44, no. 4, pp. 248–260, 2021, doi: 10.1177/0731948721994843.

[62] N. A. Martaputri, A. Muhtadi, J. Hukom, and D. Samal, "The Correlation between Emotional Intelligence and Academic Achievement: A Meta Analysis Study," *Jurnal Pendidikan Progresif*, vol. 11, no. 3, pp. 511–523, 2021, doi: 10.23960/jpp.v11.i3.202102.

[63] I. N. I. Wiradika and H. Retnawati, "Contextual Learning in Elementary School: a Meta Analysis," *Progres Pendidikan*, vol. 2, no. 3, pp. 174–182, 2021, doi: 10.29303/prospek.v2i3.187.

[64] C. Y. Eviyanti, E. Surya, E. Syahputra, and M. Simbolon, "Improving the Students' Mathematical Problem Solving Ability by Applying Problem Based Learning Model in VII Grade at SMPN 1 Banda Aceh Indonesia," *International Journal of Novel Research in Education and Learning*, vol. 4, no. 2, pp. 138–144, 2017.

[65] E. Surya, F. A. Putri, and Mukhtar, "Improving Mathematical Problem-Solving Ability and Self-Confidence of High School Students Through Contextual Learning Model," *Journal on Mathematics Education*, vol. 8, no. 1, pp. 85–94, 2017, doi: 10.22342/jme.8.1.3324.85-94.

[66] R. M. Pradyumnati and I. Harta, "High School Mathematics Enrichment Book to Facilitate Students' Problem-Solving Ability," *Al-Jabar: Jurnal Pendidikan Matematika*, vol. 10, no. 1, pp. 67–77, 2019, doi: https://doi.org/10.24042/ajpm.v10i1.3736.

[67] N. Shida, Sharifah, Hanifah, Norulhuda, and A. Halim, "The Influence of E-learning Towards Metacognitive Enhancement in Mathematical Problem Solving," *International Journal of Emerging Technologies in Learning*, vol. 14, no. 20, pp. 165–173, 2019, doi: 10.3991/ijet.v14i20.11466.

[68] R. Kladchuen and J. Srisomphan, "The Synthesis of a Model of Problem-Based Learning With the Gamification Concept to Enhance the Problem Solving Skills for High Vocational Certificate," *International Journal of Emerging Technologies in Learning*, vol. 16, no. 4, pp. 4–21, 2021, doi: 10.3991/ijet.v16i14.20439.

[69] M. A. Al-Khateeb, "The Effect of Teaching Mathematical Problems Solving Through Using Mobile Learning on the Seventh Grade Students' Ability to Solve them in Jordan," *International Journal of Interactive Mobile Technologies*, vol. 12, no. 3, pp. 178–191, 2018, doi: 10.3991/ijim.v12i3.8713.

[70] L. Morales-Maure, O. García-Marimón, A. Torres-Rodríguez, and A. Lebrija-Trejos, "Cognitive Skills through the Cooperative Learning Strategy and Epistemological Development in Mathematics of Freshmen University Students," (in Spanish), *Formación universitaria*, vol. 11, no. 2, pp. 45–56, 2018, doi: 10.4067/s0718-50062018000200045.

[71] R. I. Herrada Valverde and R. Baños, "Cooperative Learning Experiences in Mathematics," (in Spanish), *Revista multidisciplinar de educación*, vol. 11, no. 23, pp. 99–108, 2018, doi: 10.25115/ecp.v11i23.2131.

[72] M. K. Cho and M. K. Kim, "Investigating Elementary Students' Problem Solving and Teacher Scaffolding in Solving an Ill-Structured Problem," *International Journal of Education in Mathematics, Science and Technology*, vol. 8, no. 4, pp. 274–289, 2020, doi: 10.46328/IJEMST.V8I4.1148.

[73] A. Munadlir, "School Strategy in Multicultural Education," (in Indonesian), *JPSD: Jurnal Pendidikan Sekolah Dasar*, vol. 2, no. 2, pp. 114–130, 2016, doi: http://dx.doi.org/10.26555/jpsd.v3i1.6030.

[74] A. Bildiren and T. Kargın, "The Effects of Project Based Approach in Early Intervention Program on the Problem Solving Ability of Gifted Children," *Egitim ve Bilim*, vol. 44, no. 198, pp. 343–360, 2019, doi: 10.15390/EB.2019.7360.

[75] J. A. S. Vega, M. E. M. La Riva, V. H. Fernández Bedoya, J. L. A. B. Baldárrago, and S. E. P. Díaz, "Learning Strategies in Mathematics for the Participants of an Alternative Basic Education Centre," *International Journal of Scientific and Technology Research*, vol. 8, no. 11, pp. 82–85, 2019.

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